Journal of
Electrical & Electronic Systems
ISSN: 2332-0796

Research Article | Open Access

Modified Cable Insulation Characteristics Using Nano Composites for the Nuclear Power Plant

Said ESA[1], Othman ES[1], Ezz-eldin M[2], Taha H[2] and El-Kattan W[2]*

[1]*Electrical Engineering Department, AL-Azhar University, Cairo, Egypt*
[2]*Egyptian Nuclear and Radiological Regulatory Authority (ENNRA), Cairo, Egypt*

Abstract

Nowadays, The Nuclear Power Plant (NPP) Lifetime can be extended to around 80 Years; This Is Assist to Recommend the Modifications Some Properties of Polymeric Cross Linked Polyethylene (XLPE) Cable Insulation. This Work is A Laboratory Implementing the Nano-fillers as Silicon Dioxide (Sio_2) and Clay to Enhance Cable Insulation. The Volume Resistivity, Capacitance, Dielectric Loss, Tensile Strength and Elongation Properties Were Tested and Measurement for the Nanorized Samples. Furthermore, These Measurements Have Been Carried Out for the (XLPE) with Modified XLPE/Sio_2 and XLPE/Clay, at Additive Concentration of 1, 2.5, 4 and 5 Weight Percentage (Wt%). The Officially Documented Results Have Been Provided Much Better Cable Electrically Insulation and Mechanically Profile. A 205% and 189% for Volume Resistivity and Instance were improved for The XLPE/Sio_2 and XLPE/Clay Respectively, and The Analytical Calculations were in Agreement with the Experimental Results.

Keywords: XLPE; Nano-fillers; Cable insulation; Electrical and mechanical properties

Introduction

The nuclear power plant life time is in range from 40 to 60 years. The federal regulators are considering increasing the life time of these nuclear power plant licenses to be 80 year [1-3]. This can only occur with some developments in polymeric cable insulation, which can be achieved through combined the nano-fillers with the polymer of cables. There were many types of nano-fillers which use in combined of polymers as silicon dioxide (SiO_2), aluminum dioxide ($A1_2O_3$) and titanium dioxide (TiO_2) [4-6]. This combined made new materials called polymer nanocomposites (PNC) [7,8]. PNC adds several advantages as: improving the specific properties and electrical properties of cable insulators, transformers and power capacitors. That plays an important role in reducing the cost of industry and prolongs the life time of cables [4-6].

On the other hand, nano-fillers have a prominent feature of extended surface area which changes the structure and behavior of the polymer that makes the atoms increased on the surface, thus reduction of internal space charge and energy. The interaction region between the polymer chains and the nano-particle is the cause of trapping process. So, nano-fillers are responsible for carrying charges to the interaction regions. Thus, internal charges are reduced from the composite materials. When the interfacial interaction region between the nano-fillers and the base polymer matrix is strong, the composite material tends to be reinforced, thus this material is improved and enhanced [9].

Reliability of the Cables Operating in Nuclear Power Plant

NPP is usually estimated by the condition monitoring tests followed by accelerated aging. This approach is necessary as with increasing service time cable insulations and jackets, degrade gradually predominantly due to exposure to two adverse stressors associated with gamma radiation and elevated temperatures. At present, various procedures were implemented for conducting the initial and on-going qualifications of the NPP cables [10].

Materials Platform

XLPE cable can be considered the best one for transmission and distribution cables, that because its' excellent electrical and physical properties [11,12]. The Low Density of Polyethylene (LDPE) is used as a commercially available material supplied from El-Sewedy Electric Egyplast, of Egypt. The LDPE was mixed with The Luperox 231M90 component for cross linking, and blend with IRGANOX B 225 component for providing Long term thermal stability, and add IRGANOX PS 802 component for a heat stabilizer in combination with a phenolic antioxidant.

In this work, nano-silica SiO_2 as (AEROSIL 300) and nano-clay as (CLOISITE) was used for mixed to XLPE cable insulation, for improving and increasing life time cable insulations by enhancing the electrical and mechanical properties.

CLOISITE additives consist of organically modified layered magnesium aluminum silicate platelets [13,14]. SiO_2 nanoparticles provided as fumed silica with specific surface area 380 $m^2g^{-1}$and particle diameter range 3–15 nm [15]. These two types of nano materials are mixed with the insulation of the cables separately in the following proportions and are 1%, 2.5%, 4%, and 5 wt%.

Sample Preparation

1. All ingredients and the polymer material blended and compounded in pilot extruder planning (Figure 1). Extruder supplier has Screw diameter 45 mm for squeezing the ingredients with heating at 120 C°, to integrate the components homogenously. The obtained granules had been cooled by cold water, and then dried by hot air at 55-65°C. 2. The obtained compound granules had inserted to hot press instrument

***Corresponding author:** El-Kattan W, Egyptian Nuclear and Radiological Regulatory Authority (ENNRA), Cairo, Egypt, E-mail: binkpenther@yahoo.com

Received January 17, 2019; **Accepted** February 25, 2019; **Published** March 05, 2019

Citation: Said ESA, Othman ES, Ezz-eldin M, Taha H, El-Kattan W (2019) Modified Cable Insulation Characteristics Using Nano Composites for the Nuclear Power Plant. J Electr Electron Syst 8: 298. doi: 10.4172/2332-0796.1000298

(Figure 2), to mold at 180 C◦ for 15 minutes, and then cool to 60°C under pressure 300 Pascal (Pa) to obtain press molded sheets as a result form. The

Sheets thicknesses were 1- 2 mm, with dimension 20 x 20 cm.

3. These press molded sheets were cut to two types:

a) Dumbbell shape samples, by using Dumbbell shape cutter instrument (Figure 3), according to ISO-527, for testing the tensile strength and elongation.

b) Cubic shape samples with dimension 10 x 10 cm, and 100 mm diameter (Figure 4), for testing the electrical properties. All the experimental measurements were carried out at El-Sewedy, Electric Egyplast laboratories, of Egypt.

Measurements

Electrical measurements

Volume resistivity: Volume resistance was measured by volume resistivity tester ASTM-D275 (Figure 5), at room temperature. The press molded sheets were inserted into the sample holder and charged for 1 min at 500 kV. The results are the average measurements of five different specimens for each sample.

Figure 1: The pilot extruder planning for blended and compounded polymer materials.

Figure 2: The hot press instrument for sheet result.

Figure 3: Dumbbell shape cutter instrument, according to *ISO*-527.

Figure 4: Cubic shape samples with dimension 10x10 cm.

Figure 5: Volume resistivity tester *ASTM-D275.*

Capacitance and dielectric loss: The capacitance and dielectric properties of the materials were measured at room temperature by Capacitance tester ASTM-D150 (Figure 6). There were two electrodes deposited into both surfaces of the specimens by sputtering, and the diameter of sputtered electrodes is 7cm. The results are the average measurements of five different specimens.

Mechanical measurements

Tensile strength and elongation: Tensile strength and elongation tests were performed according standard mechanical measurements tester (BS EN 60811) (Figure 7). The samples have Dog-bone shapes were cut parallel and perpendicular to the extrusion direction. All the tests were performed at room temperature and the final results being the average values of five replicated measurements.

Results

The results were obtained from both electrical and mechanical measurements. First, the electrical measurements which included volume resistivity, insulation resistance, electric capacitance and dielectric constant, while the mechanical measurements contained tensile strength and elongation.

Electrical measurements

Volume resistivity and insulation resistance: Figure 8 shows the comparison between the XLPE which modified with SiO_2 nano-filler and XLPE which modified with clay nano-filler. XLPE/Clay result values are illustrate that the volume resistivity of modified cable with 1 wt% and 2.5 wt% of clay is significantly, the highest results and also closed values. While, adding 2.5 wt% and 4 wt% of clay, significant steep reduction of the volume resistivity depicted. On the other hand, the XLPE/SiO_2 result values are illustrated that the best values of the volume resistivity at injection with 2.5 wt% of silicon dioxide.

Figure 6: Capacitance tester *(ASTM-D150),* with two sputtered electrodes.

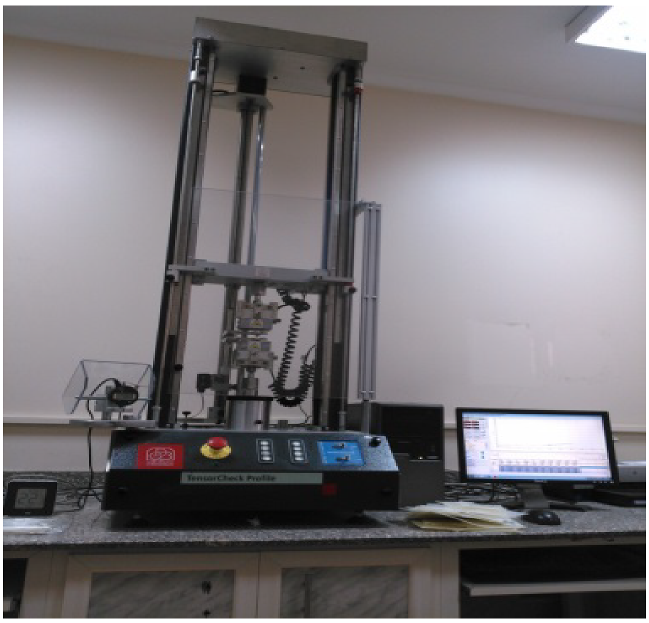

Figure 7: Mechanical measurements tester, (*BS EN 60811).*

Concluded, that the modification with the clay was displayed much improvement of cable electrical properties than the modification by SiO_2. The changes rate of volume resistivity result values for modified clay is slower than the modified SiO_2.

Indeed, the analytical calculations are the start step of any system validation, for instance the insulation resistance of the modified cable is given by equation (1):

$$R = \frac{\left(3.66\times10^{-7}\right)\times VR\times A}{t} \quad (1)$$

(R) is the insulation resistance, (VR) is the volume resistivity, (A) is the cross section area, and (t) is the thickness.

The calculated results of the modified cable insulation resistance according to equation (1) are depicted in (Figure 9), shows matching with the pattern of the measured results of (Figure 8), that the concentration 2.5wt% of the both clay and Sio_2 nano-filler will satisfy the most insulation resistance enhancement. However, the increasing of the mixed nano-fillers augments the insulation resistance up to around 5wt% [16]. This work optimizes experimentally the percentage added value of the nano-fillers that can improve the electrical properties. The additive percentage 2.5 wt % can be considered the optimized value in contrast with both the nano-fillers cost and the cable properties improvement insulation resistance 5800 SiO_2 and 5549 clay. Furthermore, volume resistivity augmentation grants higher breakdown voltage as well as current of the modified XLPE cable to meet wide range of applications such as both medium and high voltages.

Electric capacitance and dielectric constant

During the limited proportional bound, the addition of nano-fillers to the cable insulation can cause a capacity increasing as shows in (Figure 10), which illustrate significant increasing in the electric capacitance for XLPE/SiO_2 cable insulator with nano-fillers concentration of 1% to 87 Pico Farad (pF) than other nano-fillers concentrations (2.5% and 4%),

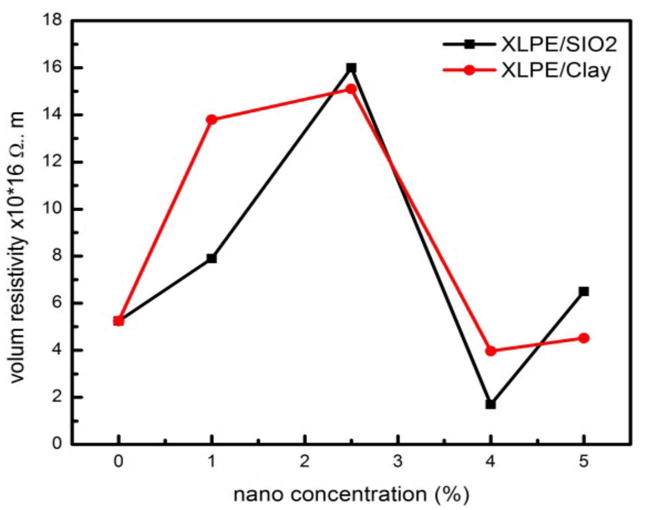

Figure 8: Histogram illustrates the comparison between volume resistivity of the XLPE which modified with SiO_2 nanofiller and XLPE which modified with clay nanofiller.

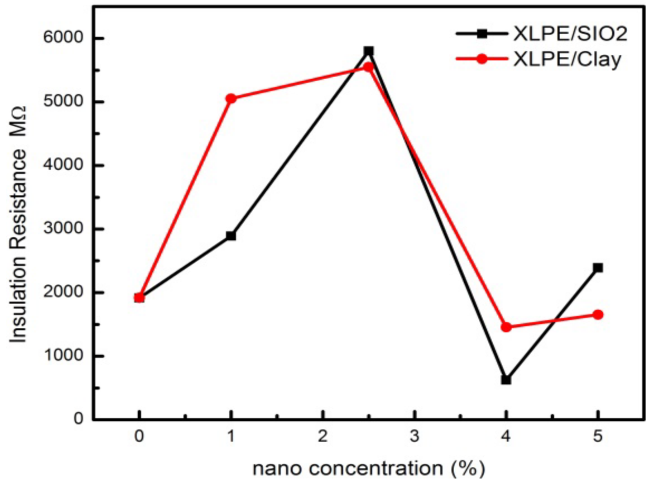

Figure 9: Histogram illustrates the comparison between insulation resistance of the XLPE which modified with SiO_2 nanofiller and XLPE which modified with clay nanofiller.

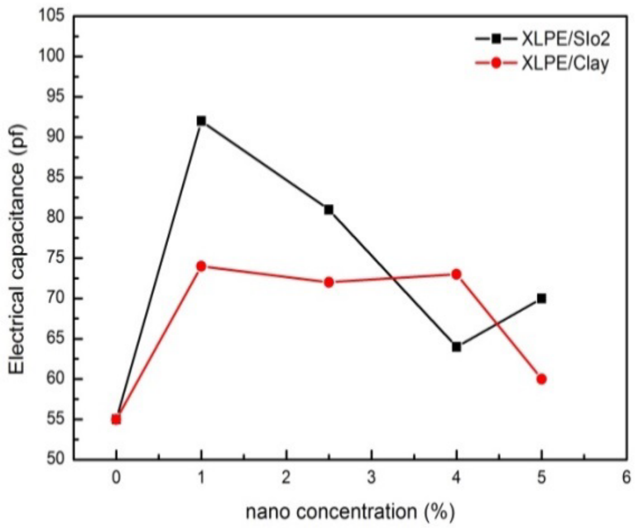

Figure 10: Histogram illustrates the comparison between electric capacitance of the XLPE which modified with SiO_2 nanofiller and XLPE which modified with clay nanofiller.

compared with zero % filling concentration (unfilled cable/XLPE) of 50 pF. Also, there were increasing in the electric capacitance for XLPE/clay cable insulator with nano-fillers concentration of 1% to 69 pF, than other nano-fillers concentrations (2.5% and 4%), compared with zero% filling concentration (unfilled cable / XLPE) of 50 pF.

Concluded that, there an significant improvement of electric capacitance according to nano-fillers concentration of 1% by XLPE/SiO_2 than different concentrations of XLPE/clay, and other concentration (2.5% and 4%) of XLPE/SiO_2, and the zero% filling concentration (unfilled cable / XLPE) of 50 pF.

Significant authenticity has been depicted and proved by the dielectric measurement results of (Figure 11) where they have the same pattern of the capacitance results of (Figures 10-13).

Mechanical measurements

The mechanical properties of neat XLPE and modified cables with

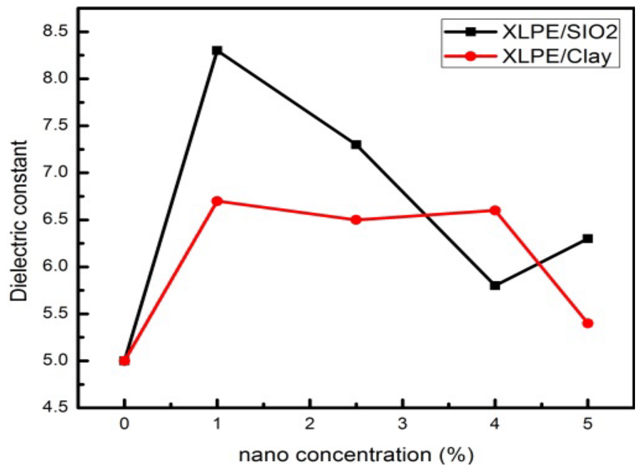

Figure 11: Histogram illustrates the comparison between dielectric constant of the XLPE which modified with SiO_2 nanofiller and XLPE which modified with clay nanofiller.

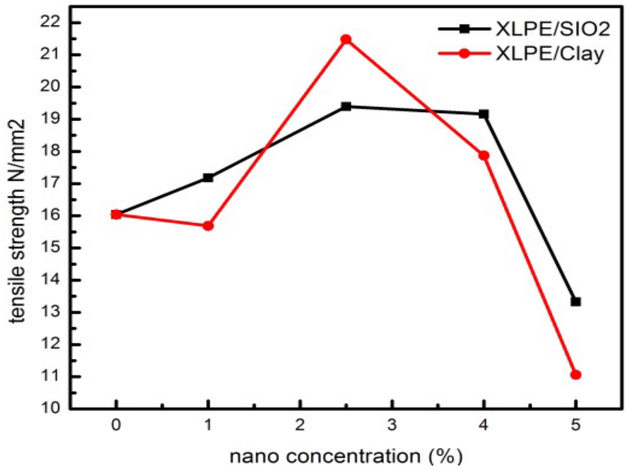

Figure 12: Histogram illustrates the comparison between tensile strength of the XLPE which modified with SiO_2 nanofiller and XLPE which modified with clay nanofiller.

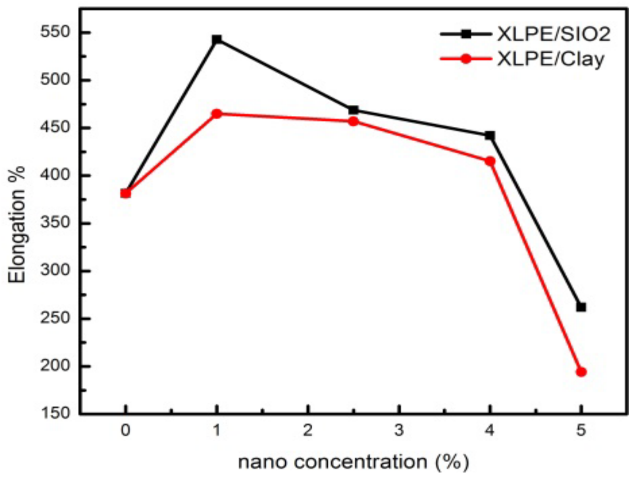

Figure 13: Histogram illustrates the comparison between elongation of the XLPE which modified with SiO_2 nanofiller and XLPE which modified with clay nanofiller.

nanocomposites, the results shown in figs.12 and 13 can be summarized as follows:

a) Both XLPE/SiO_2 and XLPE/Clay nanocomposites of 4% offer better tensile strength values of 18 N/mm^2 and 17N/mm^2respectively compared to 15 N/mm^2 for XLPE.

b) Furthermore, XLPE/SiO_2 shows enhanced properties for all mechanical characteristics; tensile strength and elongation than clay fillers.

c) Although, the mechanical characteristics is improved at 4% nano-filler this work depict much more improvement at 2.5% XLPE/SiO_2 and XLPE/Clay that offer better 21 N/mm^2 tensile strength values of and 19 N/mm^2 respectively.

In both XLPE/SiO_2 and XLPE/clay nanocomposites, the elongation improvement is directly proportional to the filler concentration such as avoiding aggregation condition.

Conclusions

In this work, nano-fillers (SiO_2 and clay) were evaluated for improving and increasing life time of XLPE cable insulations by enhancing the electrical and mechanical properties. The results was clearly illustrate that many of electrical and mechanical properties were improved as volume resistivity, insulation resistance, electrical capacitance, dielectric constant, tensile strength, and elongation. A 205% and 189% for volume resistivity and instance were improved for the XLPE/SiO_2 and XLPE/clay respectively. Finally, we recommended using 1% concentration of SiO_2 than other concentrations of clay nano-fillers for some developments in polymeric cable insulation production.

Reference

1. York RJ, Ulrich JB, Murphy G, and Prather DG (2015) Mitigation of aging in low voltage power cables in nuclear power plants. . University of Tennessee Honors Thesis Projects.
2. Huber MF (2018) Going Long Term: US Nuclear Power Could Extend Operating Life to 80 years. IAEA.
3. Alshaketheep T, Murakami K, Sekimura N, Itoi T (2016) In search of extendable conditions for cable environmental qualification in nuclear power plants. J Nucl Sci Technol 53: 1735-1741.
4. Yaacob MM, Kamaruddin N, Mazlan NA, Noramat NF, Aman A et al. (2012) Electrical Characteristics of Polyvinyl Chloride with Wollastonite Filler for High Voltage Outdoor Insulation Material. Jurnal Teknologi 64: 1-7.
5. Sharma AL, Thakur AK (2010) Improvement in voltage, thermal, mechanical stability and ion transport properties in polymer□clay nanocomposites. J Appl Polym Sci 118: 2743-2753.
6. Pleşa I, Noţingher PV, Schlögl S, Sumereder C and Muhr M (2016) Properties of polymer composites used in high-voltage applications. Polymers 8: 173.
7. Fréchette MF, Reed CW (2006) On molecular dielectrics in their role in-5shaping and controlling nanodielectrics. In Electrical Insulation and Dielectric Phenomena PP: 333-337.
8. Nelson JK (2010) Background, principles and promise of nanodielectrics. Dielectr Polym Nanocomposites PP: 1-30.
9. Tanaka T, Bulinski A, Castellon J, Frechette M, Gubanski S, et al. (2011) Dielectric properties of XLPE/SiO2 nanocomposites based on CIGRE WG D1.24 cooperative test results. IEEE Trans Dielectr Electr Insul 18: 1482-1517.
10. Przybytniak G, Boguski J, Placek V, Verardi L, Fabiani D, et al. (2015) Inverse effect in simultaneous thermal and radiation aging of EVA insulation. Express Polym Lett 9: 384-393.
11. Nelson JK, Fothergill JC (2004) Internal charge behavior in nanocomposites. Nanotechnology 15: 586-595.
12. Fothergill JC (2007) Ageing, space charge and nanodielectrics: Ten things we don't know about dielectrics. IEEE Inter Conf Solid Dielectr, Winchester PP: 1-10.
13. Moisala A, Li Q, Kinloch IA, Windle AH (2006) Thermal and electrical conductivity of single- and multi-walled carbon nanotube-epoxy composites. Compos Sci Technol 66: 1285-1288.
14. Li C, Zhao H, Zhang H, Wang Y, Wu Z, et al. (2018) The role of inserted polymers in polymeric insulation materials: insights from QM/MD simulations. 24: 73.
15. Jayanthi P, Sugumaran CP (2013) Analysis on Electrical and Mechanical Properties of Cable Insulation With Nano Composites. Department of High Voltage Engineering, College of Engineering Guindy, India.
16. Thenthiruppathi T, Harish RK, Ramkumar R (2014) Analysis on Dielectric and Mechanical Properties of Power Cable with Nano Composites. Department of Electrical & Electronics Engineering, India.